Miniature Vibration Isolation System (MVIS)

Program Status

DARPA Technology Interchange Meeting
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MVIS Objectives

- **Objectives:**
  - Develop a miniature and scaleable active/passive isolation architecture for direct loadpath insertion
  - Provide >20dB reduction of vibration transmission from bus to payload over a broad (1-200 Hz) range

- **Desired Features:**
  - Multi- point connections with hybrid active/passive isolators.
  - Local control at each attachment point, global control from central processor
  - Allows 6 dof isolation and suppression in small package for retrofitting
  - Re-programmable to meet various mission needs

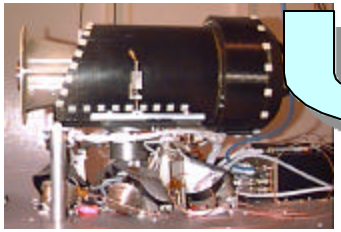
- **Applications:**
  - Application for operation of high-precision optical payloads on non-precision satellite busses
  - Small package, retrofitable, modular and inexpensive jitter reduction system
  - Application for quiet submarine decks with proper scaling of internal components
  - Applicable to micro-satellite missions as well as payloads for larger satellites

MVIS Team

- Program Manager - Tim Hintz
- Application Engineer - Jack Jacobs
- Technical Director - Torey Davis / Dave Osterberg
- Lead Electrical - Rick Self
- Active Stage Design - Dan Quenon
- Passive Stage Design - Paul Buchele
- Control System Modeling - Jim Boyd
- Launch Lock Design - Steve Hadden

MVIS Requirements

STRV-2 VISS PERFORMANCE GOALS



MVIS PERFORMANCE REQUIREMENTS

MVIS APPLICATION REQUIREMENTS (JITTER / ENVIRON)

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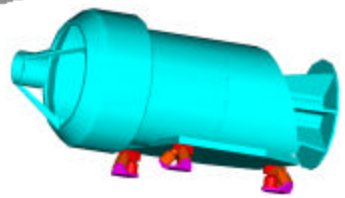
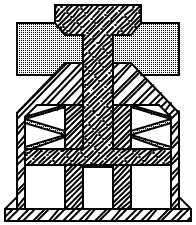
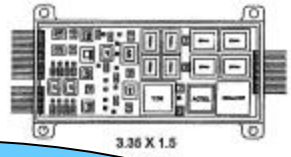
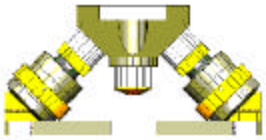




ISOLATOR REQUIREMENTS ACTIVE / PASSIVE



LAUNCH LOCK REQUIREMENTS



CONTROL ELECTRONICS REQUIREMENTS

MVIS Requirements (cont.)

- Based on detailed analysis of:
  - current noise generating components on spacecraft (RWA's, cryocoolers, gimbals, etc.)
  - Space station quiet experiment requirements (active and passive)
  - Jitter specifications from planned missions (NGST, SMV, SIM, SBL, PF, SBIRS-Low)

Paramater	Units	Requirement
Overall Isolation	-	-20 db from 5 to 200 Hz
Isolator Module Weight	lbs	<1.5
Payload Weight	lbs	2-100 (22.5 nominal)
Active Stage Stroke	in	+/- 0.002
Active Stage BW	Hz	0.5 to 100
Passive Stage Break	Hz	8
Passive Stage BW	Hz	5 to 200
Passive Stage Stroke	in	+/-0.008
Passive Damping Coef.	lbf-sec/in	2.64
Sensor Resolution	grms	<0.0003
Active Stage Drivers	-	Local with module
Controller Electronics	-	Local and Global
Packaging Volume	cubic in	<8

MVIS Schedule and Milestones

- **OCT 99 - Received Authorization to Proceed with the contract**
- **Nov 99 - Completed Fly Sheet specification**

  Identified need for displacement amplifier
- **Dec 99 - Completed "Best Candidate" isolator concept**
- **Jan 00 - Completed Systems Requirements Review**
- **Feb 00 - Placed Bellows on order**

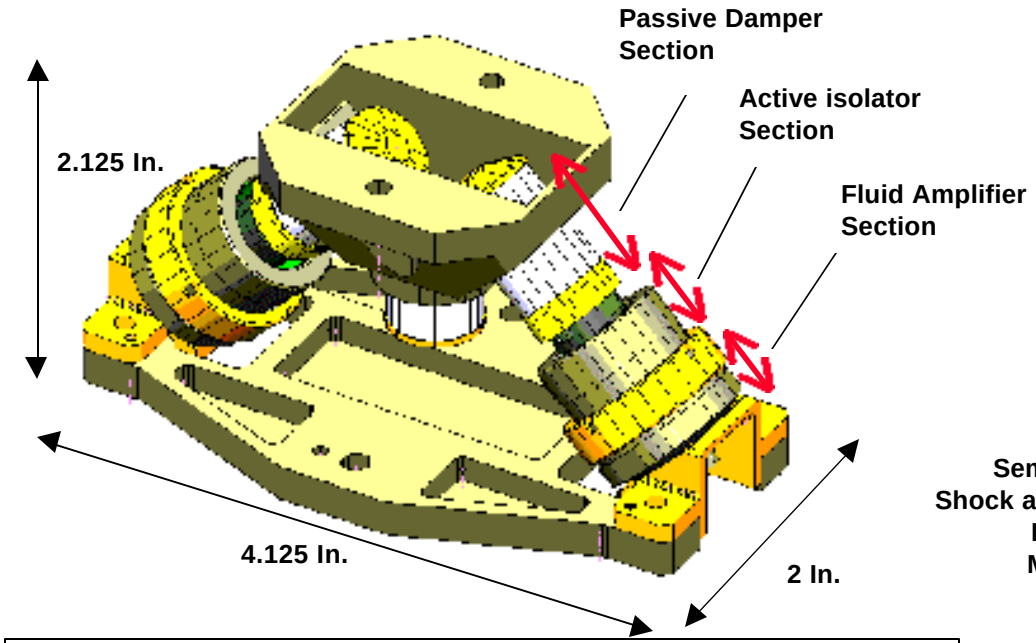
  Received Piezoelectric actuator and accelerometer

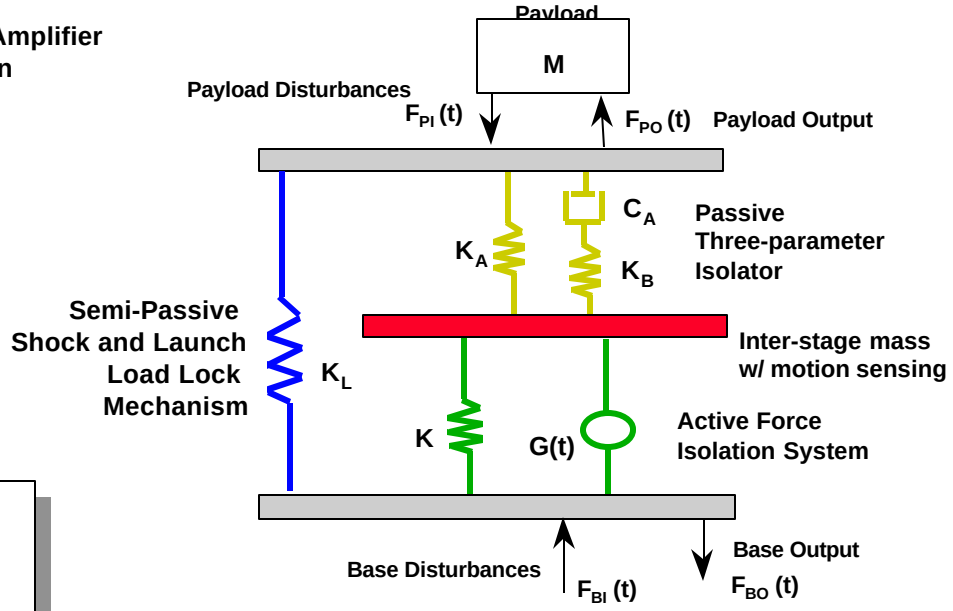
  Program placed on hold due to funding constraints
- **Mar 00 - Program on Hold**
- **May 00 - Received additional funding to complete design and fabrication of a bipod actuator.**
- **June 00 - Expect to receive the bellows order**
- **Aug 00 - Expect to complete bi-pod open loop test.**

MVIS Accomplishments

- Completed preliminary design phase
  - Active stage design complete
  - Passive stage design complete
  - Fluid amplifier design complete (7:1)
  - Controller trade study complete
  - Piezo driver design complete/partial build
  - Completed preliminary Matlab simulations
  - SMA launch lock design conceptualized
- Ordered most demonstration parts (awaiting funds for assembly/test)
- Have shown 50:1 improvement in isolator/payload mass ratio from conventional designs
- Have baselined flexible programmable and retrofittable architecture for spacecraft payload applications

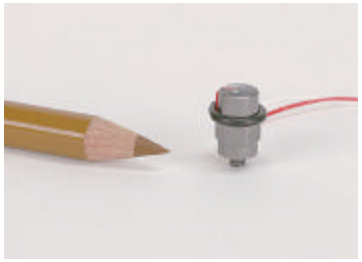
MVIS Preliminary Layout





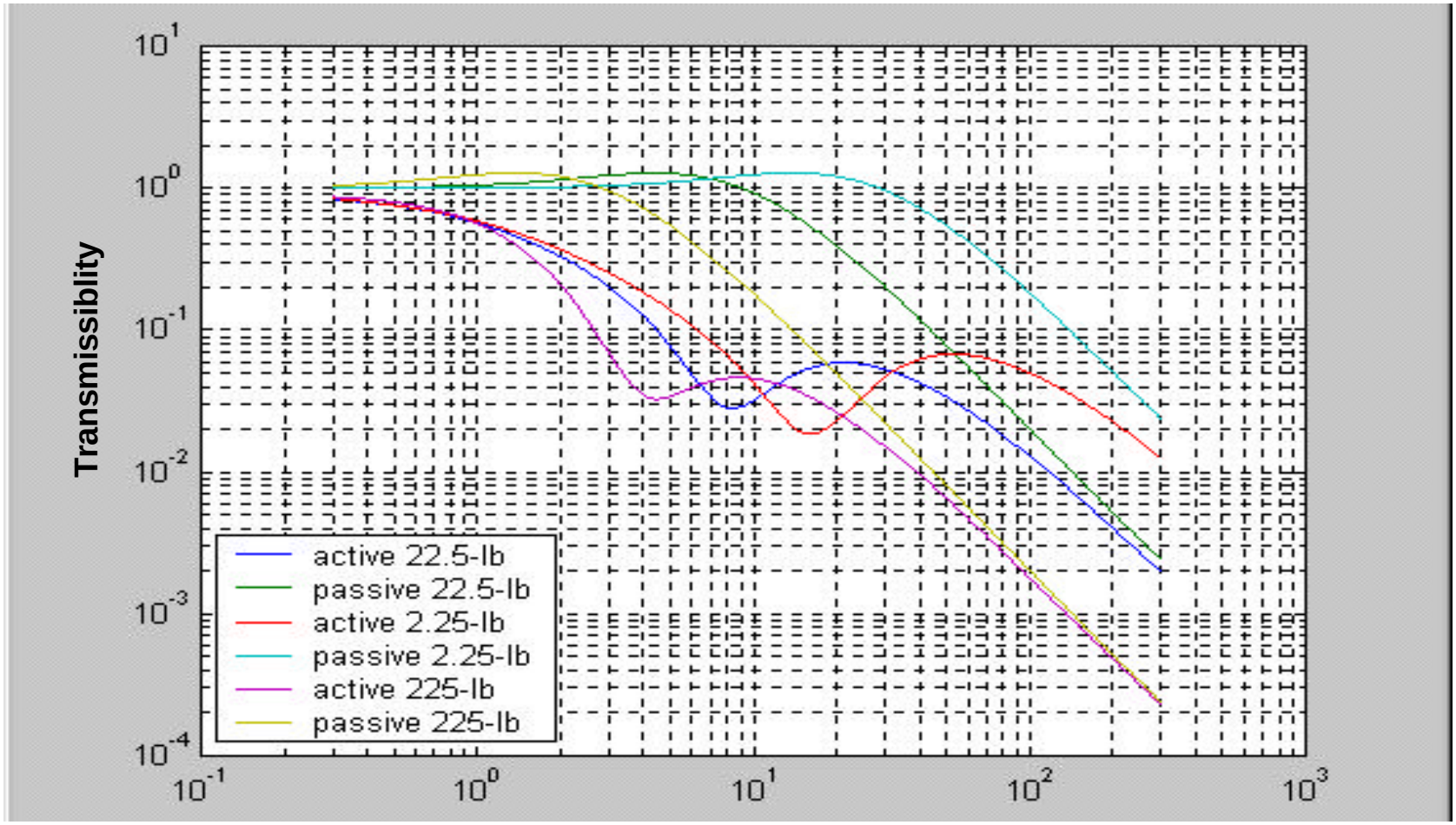
- **Demonstration Unit Features**
  - Hybrid passive/active unit
  - 7:1 fluid amplification of piezo stroke
  - Integrated accelerometer in each active stage
  - Thermaly compensating fluid bellows (no pointing)
  - Dumb base unit capable of electronics integration
  - 8 Hz Passive break
  - Hybrid system control from 0.1 to 200 Hz
  - Capable of launch lock integration

MVIS Isolator Layout (Demo Unit)



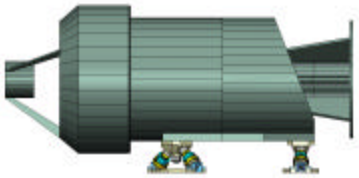
MVIS Predicted Performance

Matlab predicted transmissibilities for nom, tiny, and huge payloads, active vs openloop; retuned active and damping



MVIS Lessons Learned

Parameter	MVIS	SUITE	VISS
Payload Mass	2-100 lbm	13.7 lbm	33 lbm
Isolation	-20 dB at 5-200 Hz	-20 dB at 5-200 Hz	-20 dB at 5-200 Hz
Active Stroke	0.003 pk-pk	0.0012 pk-pk	0.080 pk-pk
Passive Stroke	0.010 pk-pk	0.030 pk-pk (TBR)	0.080 pk-pk
System Passive Damping	Q<2 for temp range between –20 and 40°C	8<Q<10 for temp range between 10 and 30°C	Q<2 for temp range between –20 and 40°C
System Power	8-27 Watts	20-30 Watts	40-55 Watts
System Mass	3.5 lbm	27.8 lbm + Electronics	34 lbm
Mass Percentage	>3.5%	>100%	>100%



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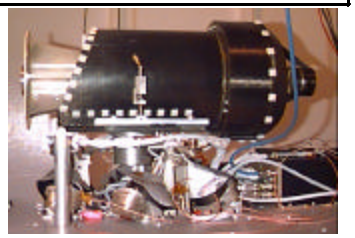
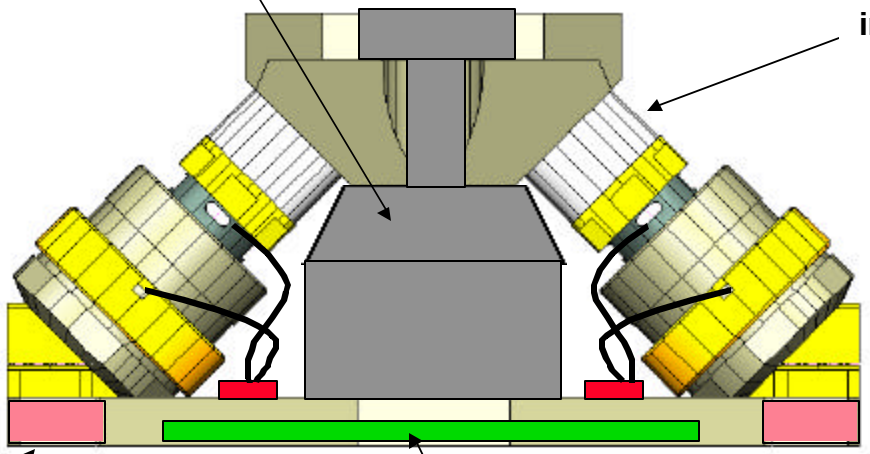
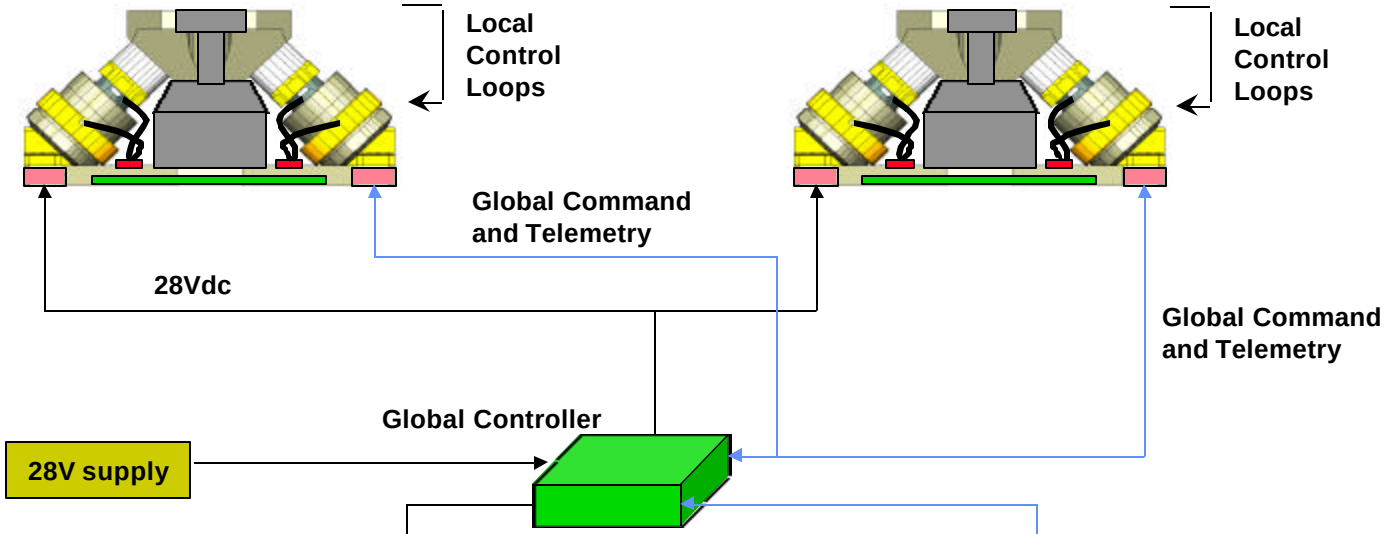


- MVIS clearly shows some promise for the right applications (Small-medium payloads, small strokes, no steering)
- "Build it (test it ,prove it), and they will come!

MVIS Next Steps



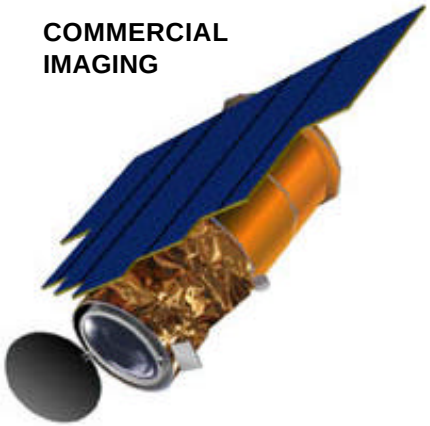
MVIS Next Steps (cont.)



MVIS Applications

- MVIS will fill a need for low cost, small size, low frequency on-orbit vibration isolation of medium to small payloads on future missions where pointing stability, and accuracy are of primary importance.
- Mission examples: (NGST, TPF, SBIRS-Low, SMV, SIM, Discoverer II, Commerical Imaging and Special Programs)
  - Cryo-coolers
  - Focal Plane Arrays
  - RWA's
  - Whole Laser Communications Terminals

COMMERCIAL IMAGING



Summary

- MVIS shows real promise for NASA and DoD jitter sensitive missions and is retrofittable to most designs
- Most demonstration components have been designed, ordered and delivered
- Remaining funds will allow for open loop single hybrid strut testing
- Anticipated funds will allow for dual strut (single module) closed loop testing
- Fluid amplifier design is very compact and could be applied to other CHAP programs
- Continuing to work with customers for ground/flight demonstration opportunities

BACKUP SLIDES

Actuator Active Stage Options

Summary of piezoelectric possibilities for Demo unit

Vendor and Model number		Open loop travel		Max force		Operating voltage range for max travel	Diameter		Length		Stiffness		Capacitance	Electrical Interface
		µm	µin	N	lb.	V	mm	in	mm	in	N/µm	lb/µin	nF	
DynaOptic Motion	CTC-PSt 150V 150/2x3/5	3	118	135	30.3	150	5.1	.2	5	.2	45	0.257	70	Red and black leads
Physik	P249.10	5	197	100	22.5	1000V	6.5	.25	6.5	.25	20	0.114	6	LEMO connectors and 1 m PVC cables
Physik	P802.00	6	236	1200	270	100	7	.28	9	.35	200	1.14	.7	
Kinetic Ceramics Inc.	D0210	10	394	700	157	800 V	5.1	.2	7.7	.30	70	.40		
Piezomechanik	HPSt 150/20-15/12	12	472	4800	1080	150V	22 o.d. 14.5 i.d. tube	.87 .57	13.5	.53	400	2.28	6000	2 pigtails black & red
Piezomechanik	HPSt 150/14-10/12	12	472	2000	449	150 V	15 o.d 9 i.d tube	.59 .35	13.5	.53	150	.855	2900	2 pigtails black & red
Xenetics	XIRP0510	5	197	1050	236	150	5	.2	10	.39	135	.77	210	

Biomorph

Vendor and Model number		Open loop travel		Max force		Operating voltage range for max travel	Width		Length		Stiffness		Capacitance	Electrical Interface
		µm	µin	N	lb.	V	mm	in	mm	in	N/µm	lb/µin	nF	
Piezo Systems	T220-A4-503-QM	± 1325	± .05 inch	± .33	±.074	± 90	69.9	2.75	31.8	1.25			290	2 leads
ACX	QP15N	± 407	± .016 inch	15	3.37	100	25.4	1.0	50.8	2.0			100	2 leads

Most likely PZT

Controller Assumptions

- Distributed Processor System Baselined.
- Centralized Power Supply.
- On orbit software configurability is still required.
- Each approach satisfies performance requirements.
- System power < 27 watts.
- System weight < 3.5 lbs.
- Control bandwidth of 100 Hz per channel.
- Smart local control actuator required.
- Global controller used for all topology options.
- 12-bit A/D and 8-bit D/A converter resolution is sufficient.
- Radiation Hardened design required.

Controller Trade Study

	Requirement	AIC51	80C196	DSP	MCP (viss)
Sample Frequency/BW (per ch)	1500 Hz/150 Hz (1000, 100)	900/90	8K/800	20K/2K	20K/2K
Channels	>= 2 per vertex, 6 total	1	2	up to 12	up to 8*
Temperature	-55°C to +85°C	-150,85	-55,+125	-55,125	-55,125
RAM	1Kx8/ channel	internal 128K x 8	1K internal	external	32K x 32 internal
PROM	1Kx8/ channel	internal 128K x 8	external	external	8K x 32 internal
Bus width		8	16	32	32
AD Conversion	4 channels/ CUBE	32 internal	external	external	16 internal
Sample Rate	10 ksamp per ch	160 kSPS			10 Ksps
Resolution	12 (TBR)	12			12
Accuracy	±2 bits (TBR)	10			
DA Conversion	3 channels	10 internal	3 pwm channels	external	8 internal
Resolution	8 (TBR)	10	8	10 to 14	12
Accuracy	±0.5 bits (TBR)				
Size (Board Area) Hybrid Option MCM option MCM w ASIC option	minimize	 1.75 x 2	2.5x3.5 in 2 x 3 in	5 x 7 in 3 x 4 in 2.5 x 3 in	2 x 4 in
Serial Interface	RS232/Synchronous	4/2	1/4	0/1	0/1
Power (card)	minimize	0.05Watts	1.2W	6-8W	4w
Operating Voltage	3.3 to 5 Vdc	3-5,5	5	3.3-5 ,5	±15, 5,
Radiation Tolerance	100 Krad total dose	5Krad	100Krad	1Mrad	20 Krad

Controller Conclusions

Trade study performed based on:

- Recurring Cost
- Non Recurring Cost
- Radiation tolerance
- Weight
- Power
- Board Area
- Performance Margin
- Expandability
- Reliability (parts count)
- Reliability (fault tolerance)
- Legacy (software & hardware)

Results:

- Based on Best Performance (bang/buck):
  - Best Processor Candidate is to use a single 32-bit DSP card.
    - Used for both local and global digital control.
    - Per unit cost is similar regardless of processor IC.
- Based on Low Cost, High Volume and Minimal Reconfigurability:
  - local analog control and digital global control.
  - Possibility of using a smaller, lower power, less powerful processor depending upon global control requirements.
- For Demonstration Purposes:
  - Local Processor Control Baselined for on-orbit reconfiguration testing.

Piezo Driver Requirements

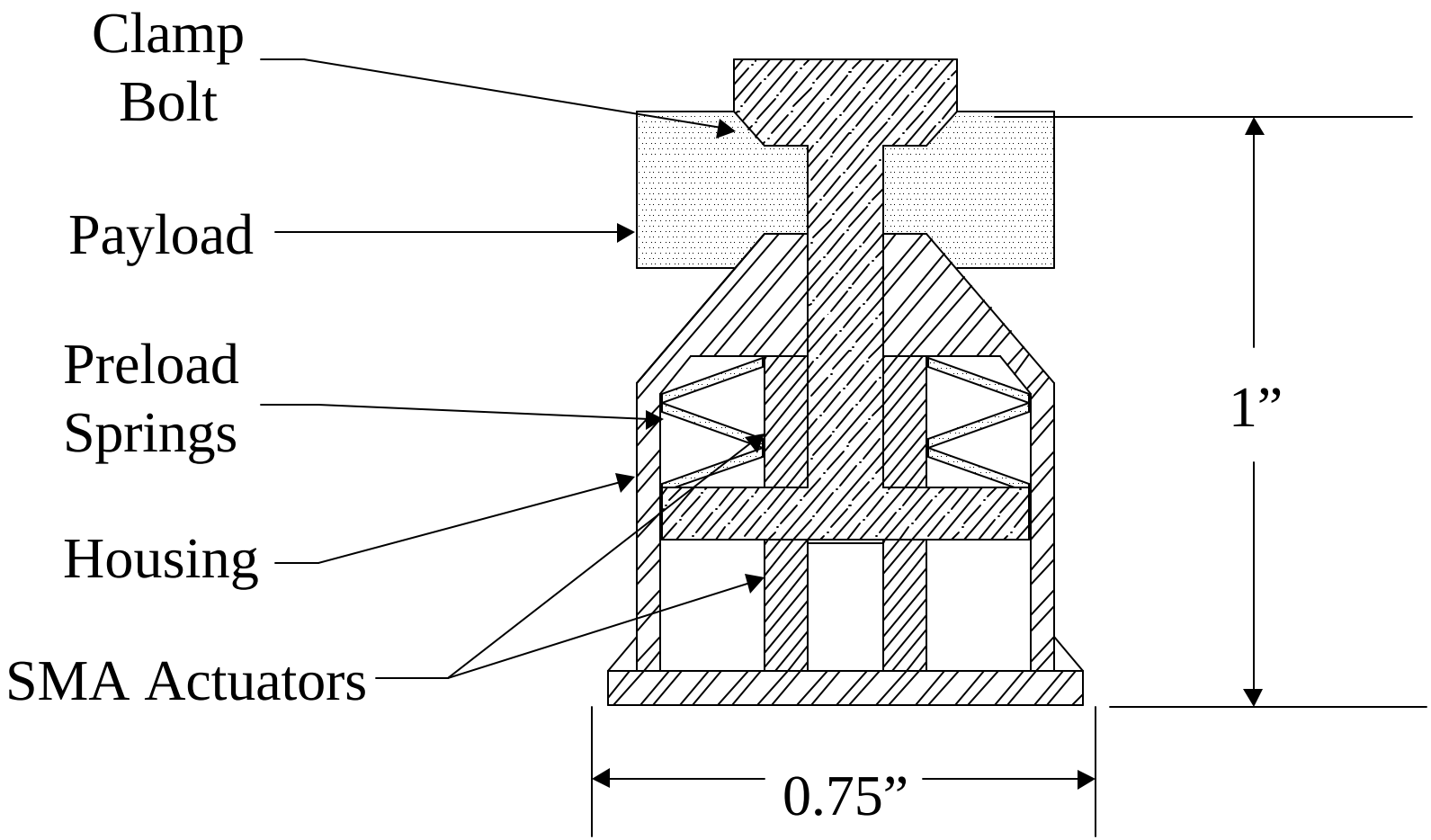
Parameter	Value	Comments
Supply Voltage Range	150 Vdc	Baseline is single 150Vdc
Usable Output Voltage Range (across Piezo)	-75V to +75V minimum	H-Bridge or Dual supply for demo unit
Output Current (peak operating @8 Hz)	16mA	Resonance Frequency 6 uF capacitance
Peak Output Current	20mA	
Efficiency	>90%	
Load Capacitance	<6.0 µF	Best Candidate is 6uF.
Amplifier Type	Bipolar Drive	
Bandwidth	DC to 1.5 kHz (goal)	0.25 to 200 Hz minimum
Command Input	0 to 10 Vdc	(TBR) Interfaced to microcontroller. Could be Filtered PWM input @ >20kHz
Output Power (Typical per channel)	<0.5 watt	(TBR)
Output Power (Continuous per channel)	2.4 watt	(TBR)
Output Power (Peak per channel)	5 watts	(TBR)
Board Size	< 2”x 1.5”	Not critical for demo unit but would like to keep as small as possible.
Channels	2	Application needs 2 drivers per cube.

Launch Lock Trades

- Actuator Candidate selection
  - Electro Mechanical actuators
  - Paraffin actuators
  - Shape Memory actuators
    - Terfenol-D
    - Nitinol

Requirement Reference No.	System Requirement
1	One Lock per Station
2	2-100 lb payload Capability
3	0 Debris
4	Factor of Safety-Yield (Fsy) of 1.0
5	Factor of Safety-Ultimate (Fsu) of 1.25
6	Actuation time < 10 min
7	Power < 40 W per Lock
8	Margin of Safety > 0
7	Size < 1” cube
8	0.15 lb per Station
9	Must be able to Re-stow payload
10	Stroke of .015”

Launch Lock Best Candidate Design



Isolator Sub-System Design

- APPLICABLE SYSTEM LEVEL PERFORMANCE REQUIREMENTS
  - PAYLOAD: OPTIMIZED FOR 22.5 LBF PAYLOAD
  - VERTICAL BOUNCE FREQUENCY: 8 Hz
  - ACTIVE STROKE: ±.0020 INCH
  - PASSIVE STROKE: ±.0080 INCH
  - VERTICAL DAMPING COEFFICIENT: 2.64 LBF-SEC/INCH
  - OPERATIONAL FREQUENCY RANGE: DC TO 200Hz
  - ISOLATION: -20dB FROM 5 TO 200Hz
  - LAUNCH LOADS: NOT APPLICABLE - LOADS TAKEN BY LOCK SYSTEM
  - ENVIRONMENT PRESSURE: <1E-6 torr
  - ENVIRONMENT TEMPERATURE: -15C TO +70C OPERATIONAL / -36C TO +70C SURVIVAL
  - SENSOR: 100mV/g SENSITIVITY, <.0003grms RESOLUTION
  - SIZE: FIT WITHIN 2”X2”X2” CUBE

- FLOW DOWN STRUT PERFORMANCE REQUIREMENTS
  - CONFIGURATION: 2 STRUTS PER STATION/45° INCLINE/ 3 STATIONS
  - AXIAL STIFFNESS: 15 LBF/INCH
  - ACTIVE STROKE CAPABILITY: >±.0015 INCH
  - PASSIVE STROKE CAPABILITY: >±.005 INCH
  - PASSIVE DAMPING COEFFICIENT: 0.88 LBF-SEC/IN

Technology Leverage for MVIS

1993 1994 1995 1996 1997 1998 1999 2000

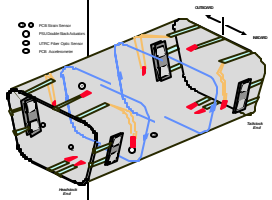
Smart Materials Initiative (DARPA)

-Small Piezo Drivers
-Manufacturing Methods
-PZT Materials and Packaging

Marine Technology Upgrade (USN)

Active Deck Mounts and New Technology insertion

SPICES (DARPA)



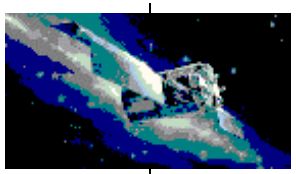
-Hiearchic Vibration Control
-Multifunctional Structures fab
-Advanced Sensors/Actuators

RITA/HUMS (Army/Navy)

Miniature Digital MEMS Sensors

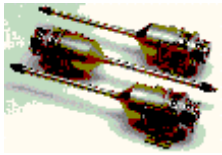
MVIS (PL/DARPA)

Mini support mount for optical and precision payload vibration control



D-Strut™ Development

Small Package and High Passive Damping (40 dB/decade)



VISS (PL)

Hybrid active/passive satellite payload vibration suppression

LEO Laser-Comm Market Thrust